The SMART|EDM_Lab at TSU

Activity Report (2017 – 2021)

(June, 2021)

David Mchedlishvili

Head of SMART|EDM Laboratory

Iv. Javakhishvili Tbilisi State University (TSU)

Executive Summary

SMART|Labs are one important pillar of the Georgian-German Science Bridge (GGSB), a scientific cooperation between a consortium of Georgian universities and institutes of Forschungszentrum Jülich (FZJ, Germany). The aim of these laboratories is to provide a possibility for outstanding young, well-educated Georgian scientists to return to Georgia, giving them a basis for their research and continuing the cooperation with their partners at FZJ.

Two such laboratories have been founded in 2017 at TSU, one of which is the SMART|EDM_Lab, which is dedicated to fundamental research in the field of particle physics. More specifically, its goal is to establish the basis for a search of Electric Dipole Moments (EDM – thus its name!) of fundamental charged particles in storage rings – as a partner in a large international collaboration (JEDI, Jülich Electric Dipole moment Investigations) working at the COSY storage ring at the Institute for Nuclear Physics (IKP) of FZJ.

The science case for the search for EDMs is exceptional, because it comprises two of the most pressing unanswered questions in contemporary physics and cosmology: (i) why is there only matter and (almost) no antimatter in our Universe – which alludes to the *puzzle of our very existence* – and (ii) what is the Nature of Dark Matter (DM)? EDMs can contribute to answering these questions, because: (i) static EDMs violate a fundamental matter-antimatter symmetry (called Charge-Parity, CP for short) and thus provide the required additional CP-violation, and (ii) oscillating EDMs could be the result of a so-called axion-field, permeating all space and being part of the material that makes up DM. Up to date, neither any EDM has been found nor Dark Matter particles have been discovered. The new storage-ring EDM method (srEDM) promises an unprecedented search sensitivity.

The present Activity Report of the SMART|EDM_Lab summarizes the contributions of the group of Georgian scientists and students under my leadership for the period from its establishment (2017) until today (2021). During this time span, the group has been working primarily on one of the essential key-components for the srEDM experiment, the so-called polarimeter (JePo for JEDI Polarimeter), which measures the polarization of a stored beam in COSY and its potential miniscule changes with time due to an EDM.

The major activities and achievements of the report period comprise:

At the SMART|EDM_Lab at TSU:

- Preparation of talks, including those of students, at meetings, workshops and conferences
- Preparation and submission of scientific/technical papers in refereed journals
- Provision of a portable Data Acquisition System for the SMART|AtmoSim_Lab
- Technical support in provision of a first "Teachers Workshop" at TSU in cooperation with JULAB

At IKP and COSY of FZJ:

- Participation the polarimeter set-up for tests in the laboratory and at COSY
- Participation in beam-times at COSY
- Analysis of experimental polarimeter data
- Simulations to understand and interpret experimental data
- …

The Report intends to demonstrate that the SMART|EDM_Lab at TSU is an unrestrained success, which serves as a focus of excellence, attracting and training future scientists and engineers in and for Georgia. The future plans for the basic research field and applied science directions are outlined as well.

Contents

1 General project overview

SMART|EDM laboratory has been founded in 2016 in the framework of Georgian-German Science Bridge (GGSB), on the bases of a mutual agreement between the Helmholtz Research Center in Jülich (Forschungszentrum Jülich (FZJ), Nuclear Physics Institute (IKP)), Shota Rustaveli National Science Foundation of Georgia (SRNSFG), Ministry of Education and Science of Georgia (MES) and Iv. Javakhishvili Tbilisi State University (TSU). After receiving a targeted grant – “Search for Electric Dipole Moments using Storage Rings (srEDM) (04/01)” from SRNSFG in February 2017, the laboratory became fully functional. In order to efficiently contribute to ongoing research activities of the international JEDI (Juelich Electric Dipole moment Investigation) collaboration, the SMART|EDM_lab was equipped with a modern apparatus with the help of SRNSFG funding. Some equipment was also donated by the Jülich center, that proved to be a great support in the launching stage.

A short list of research activities and achievements during the five years of the project duration:

- Development of a dedicated polarimeter detector for the JEDI experiment. Project participants were actively involved in the process of the concept development, construction and tests of different parts of the detector. The most of those activities have been carried out at Juelich;
- Development of a multi-channel and modular power supply for the JEDI polarimeter. Modules of the power supply have been developed at SMART|EDM_lab together with 128 channel sequential voltage monitoring system. The final assembly of the power supply and integration of the voltage monitoring system was performed in Juelich. Later, set of laboratory tests were performed resulting in greatly improved stability of the whole power supply;
- Development of the slow control and monitoring software for the power supply;
- Development of the online analysis software for the polarimeter detector;
- Development of a portable data acquisition software for Red Pitaya STEMlab 125-14 board. This portable DAQ system is used very efficiently in various laboratory tests at SMART|EDM_lab as well as at Juelich (detector sampling/checking);
- Active collaboration with SMART|AtmoSim_lab of TSU. Within the main research topic of the SMART|AtmoSim_lab – the study of the air pollution and related chemical processes in the atmosphere - the first prototype of a dedicated portable data acquisition and analysis system has been developed to work with well-established analog gas sensors by AlphaSense.

2 Work packages

Ongoing activities within the project were focused on:

- A new polarimeter: detector and target concept;
- Construction and tests of polarimeter elements, development of readout systems;
- Demonstration of polarimeter capabilities;
- Students involvement in the project;
- Educational components for students – advancing hardware and software skills, development of proficiencies for accomplishing Master and PhD theses;
- Participation in local and international conferences, publications in high-impact journals.

2.1 Polarimeter hardware

An innovative method of measuring EDM's of charged particles using storage rings (srEDM) is being developed at IKP of research center Juelich. The COSY accelerator facility is used to proof the principles of the measurement technics which rely on very precise polarization measurement of the charged beam particles in time. The existing detectors at COSY (EDDA, WASA), although initially used as temporary polarimeters for EDM test experiments, are not capable to achieve the final goals. The JEDI collaboration came to a decision to develop a dedicated polarimeter. The new polarimeter, called JePo, must fulfill the set of stringent requirements for srEDM such as high speed, high efficiency and high precision.

The detector part of the polarimeter consists of the calorimeter modules and the tracking system. The calorimeter modules are based on inorganic scintillation material – LYSO. The high density of the material and the high light yield ensures high energy resolution of the calorimeter modules. That is an important feature for measuring deuterons, allowing for a clear identification of the polarimeter reaction. Should be noted that the LYSO material is also widely used in PETs (Positron Emission Tomography) for medical imaging purposes.

The polarimeter development started with calorimeter, as it is the most important part of the detector. The development and testing of the calorimeter was progressing step by step, using extracted COSY beams initially. Now the polarimeter is already installed at COSY internal beam and is capable to efficiently measure and control the polarization. However, the tracking system is still missing (work in progress). The SMART|EDM_lab and the main participants of the related grant project have been actively involved in all phases of the polarimeter development – planning, construction, laboratory and beam tests. Some of these activities such as development of some of its supportive systems (will be discussed in details later) have been performed at SMART|EDM_lab at TSU. Others - at Jülich center, while the main participants were travelling to Germany to take part in preparation and carrying out experiments at COSY.

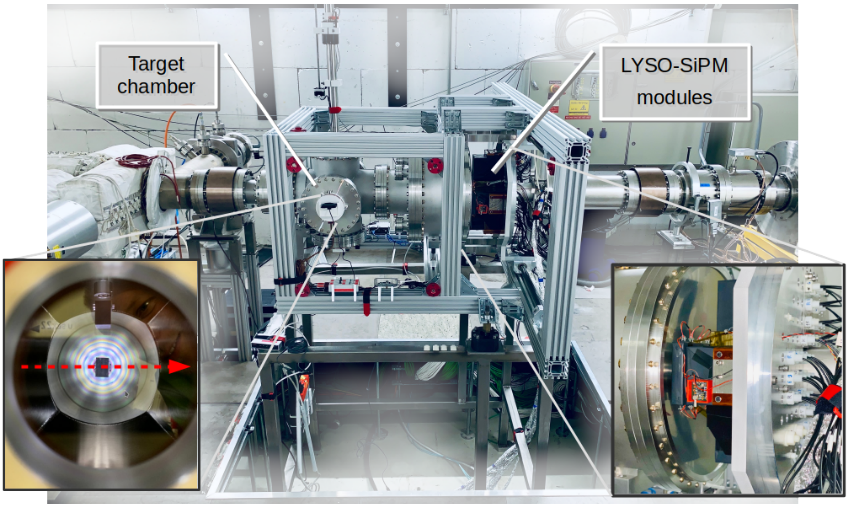


Figure 1. JePo at COSY.

At the early stage of the polarimeter development the following work packages had been identified for the SMART|EDM_lab. These were mainly focused on the development of the power supply for the detector modules and the data taking and online analysis systems.

2.1.1 Polarimeter power supply

The LYSO-based calorimeter modules of JePo are read out by SiPM arrays (Silicon Photo Multipliers). The parameters of used SiPM arrays had been carefully investigated at different voltages using a black box, where a LED flasher was installed. Short pulses from a signal generator were fed to the LED and the output of the SiPM array was monitored. This revealed a strong dependance of the output signal amplitude (collected charge) on the bias voltage of the SiPMs as shown in Figure. Taking the LYSO energy resolution alone (of about 1% for 300 MeV deuterons), this result suggests that the maximum allowable instability (including noise) of the bias voltage in the vicinity of 30 Volts should not exceed 10mV to not degrade the overall energy resolution of the calorimeter module.

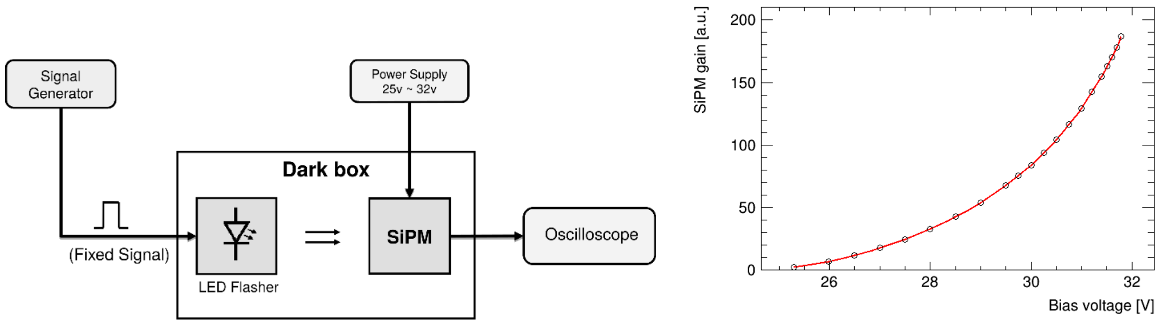


Figure 2. SiPM test schematics using a black box (left) and the obtained main result (right)

It was decided to develop linearly regulated voltage modules for biasing the SiPM arrays. The developed modules are based on UA723 precision linear regulator IC from Texas Instruments. Two features are implemented in the circuit - the remote on/off capability with slow rump up/down of the output voltage.

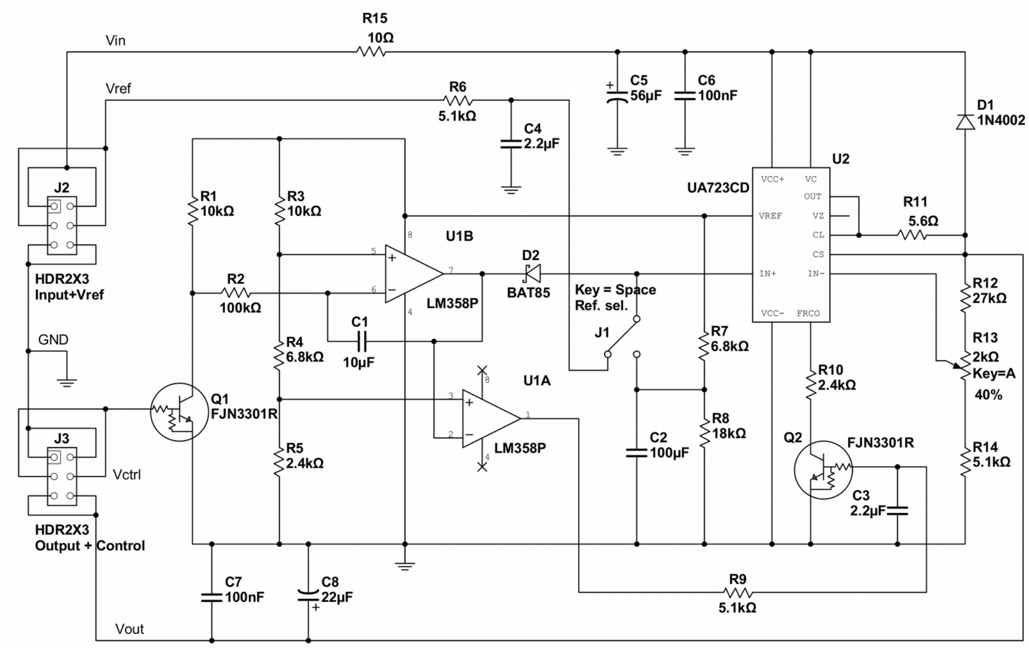


Figure 3. The schematics of the power supply module

The circuit provides possibility of using built-in voltage reference which is very helpful when using a single module alone (e.g., for testing detector modules in the lab), as well as external one. However, the detailed laboratory tests of the first prototypes of the voltage modules revealed deficiencies of the built-in voltage reference. The provided high noise level at very low frequencies does not guarantee high short-term stability of the module. Besides, the temperature stability, which is mainly affected by the stability of the voltage reference, is also worse than required. Therefore, a dedicated 5V source was developed to provide very stable common reference voltage to all voltage modules of the power supply. It is based on MAX6350 IC from Maxim Integrated and output current buffering is implemented to run many modules at the same time.

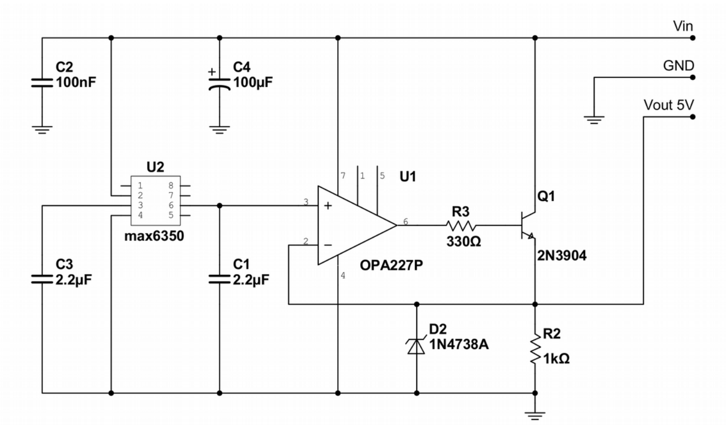


Figure 4. The schematics of the voltage reference for the power supply modules

Calorimeter modules connect to the power supply with long coaxial cables (using LEMO connectors). Although, the average current through the SiPM arrays is in the order of mAs, the cables provide substantial resistance during pulse current demands (up to 100 mA). For that reason, the SiPM supporting boards include multi-layer ceramic capacitors for charge buffering. An attempt was made to investigate such a dynamic loading on the developed voltage modules together with the SiPM boards, but without the SiPM arrays and the COSY beam. In order to simulate the SiPM loading as precisely as possible, a special circuit was developed for fast current sinking. The output signal from the programable function generator was fed to the current sink and converted to a load current, mimicking the SiPM array connected to the voltage supply module. The Red Pitaya STEMlab 125-14 development board was used to generate the signal as well as to monitor the output of the SiPM support board. The real signals from the SiPM arrays, recorded during the beam tests of the first prototypes of the calorimeter modules were used in these tests.

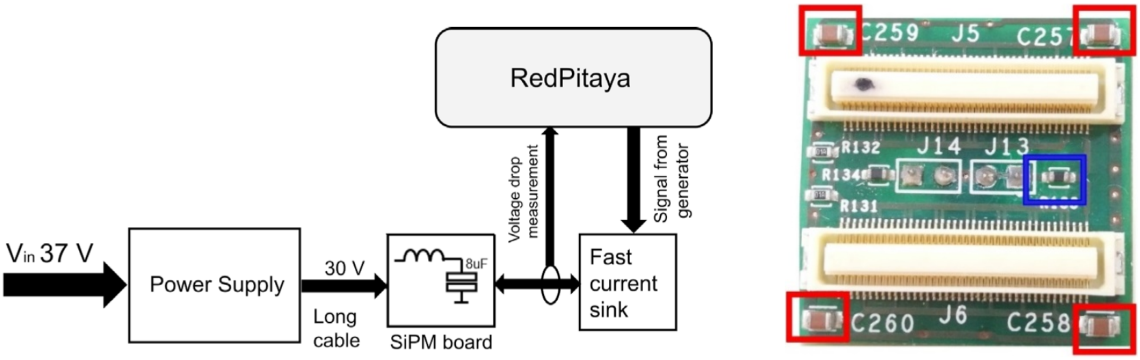


Figure 5. Left picture describes the circuit which was used to simulate the SiPM loading. A SiPM support board is shown on the right picture, where all the supporting electric components are shown.

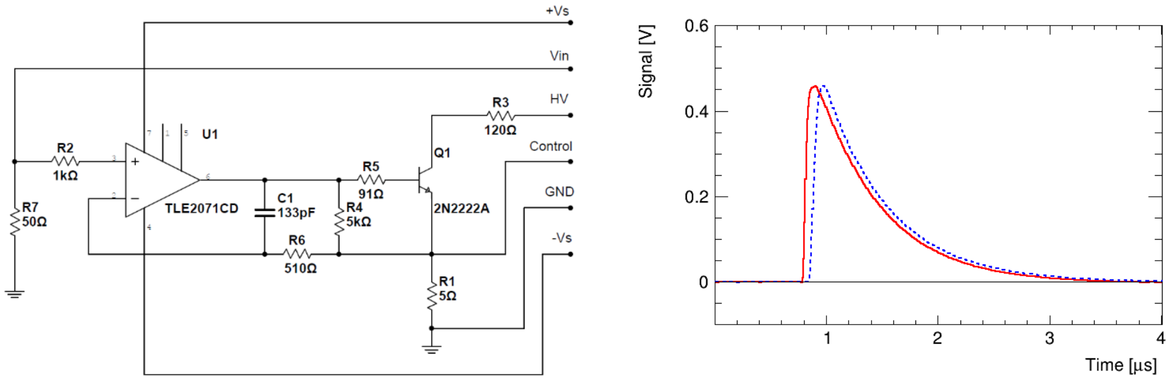


Figure 6. The schematics of the fast current sink (left) and the measured input/output signals (right). The solid curve corresponds to the input voltage signal, while the dashed curve is proportional to the output current signal.

Dynamic loading tests revealed some weaknesses of the first version of the SiPM supporting boards. It suggested to increase the total capacitance provided on board and also modify the layout. The updated board was also tested and improvements were identified.

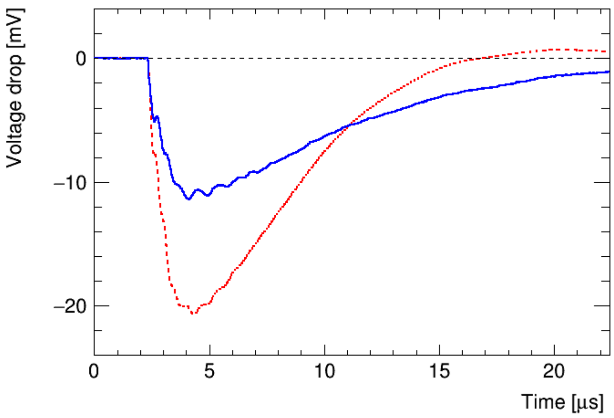


Figure 7. Measured voltage drops at the SiPM side. The dashed curve corresponds to the old version of the board, while the solid curve - updated board.

2.1.2 Voltage monitoring system

In order to monitor the output voltages of the calorimeter power supply a dedicated voltage monitoring system was developed and built at SMART|EDM_lab. The readout board is based on high quality, high speed and linear multiplexer ICs which sequentially redirect 128 different channels to the output, where a remotely controlled high precision desktop multimeter reads the voltages. The readout board and the multimeter are controlled by the same Raspberry Pi computer as the whole power supply. This is achieved by a separate IO extender board, which is controlled by the Raspberry Pi using SPI interface and provides enough output pins to control every supply channel independently.

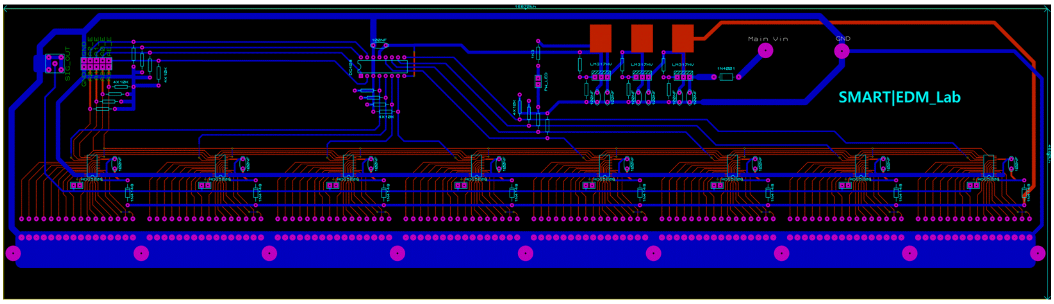


Figure 8. PCB design of the voltage monitoring board

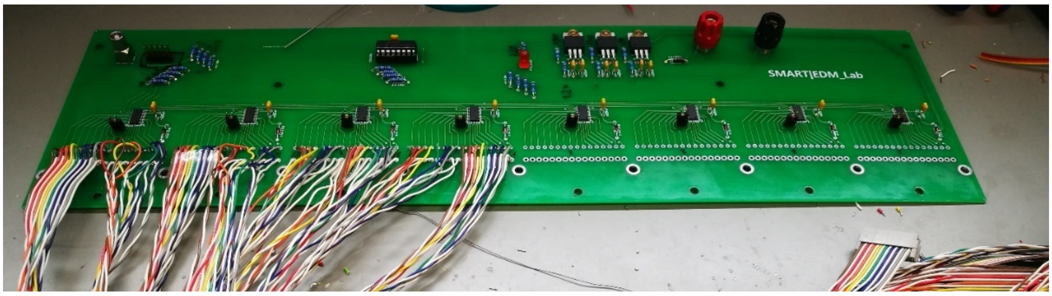


Figure 9. A fully assembled voltage monitoring board

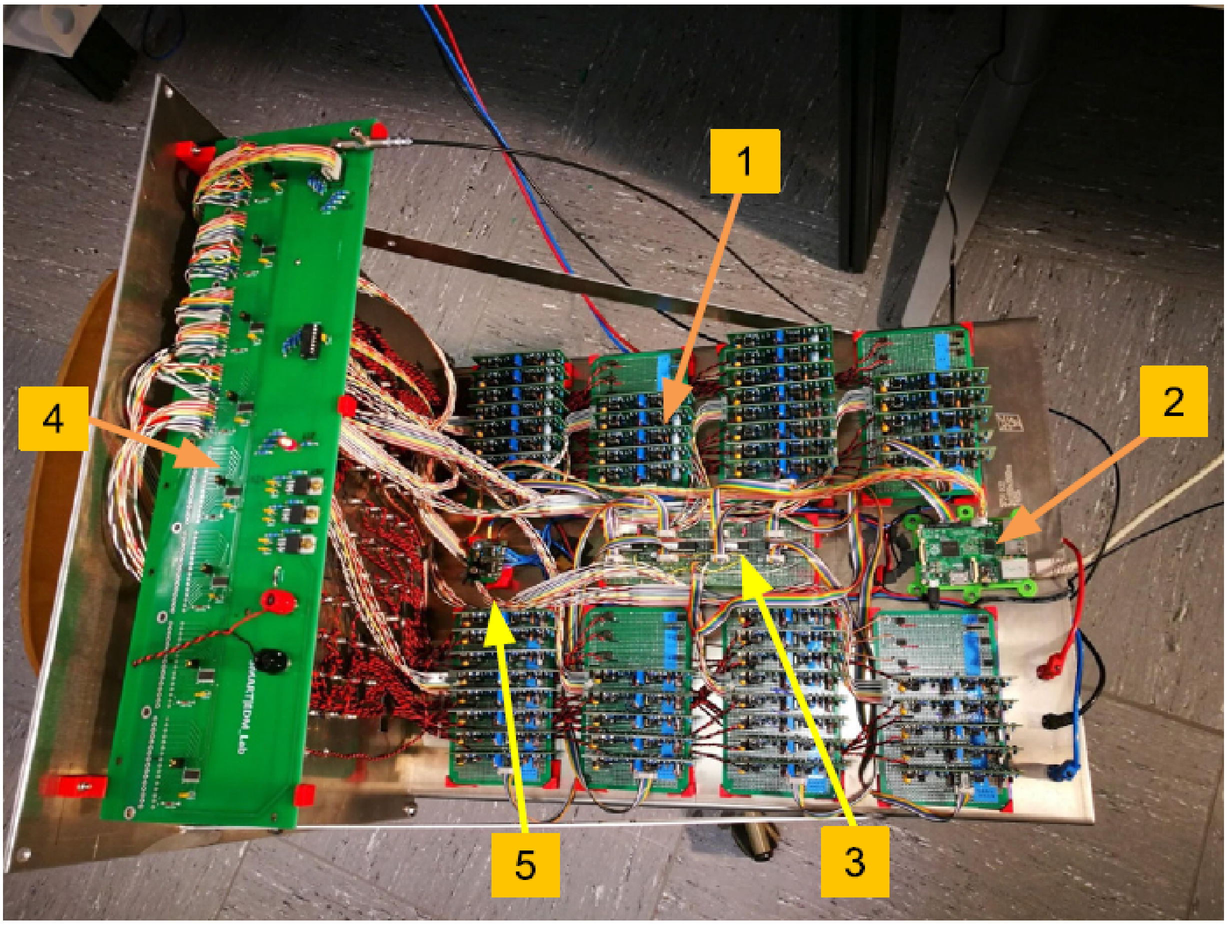


Figure 10. A fully assembled JePo power supply with 64 channels. The following parts are indicated: 1 – supply modules, 2 – Raspberry Pi, 3 – IO extender board, 4 – voltage monitoring board, 5 – voltage reference board

2.1.3 Detailed analysis and improvement of the temperature stability of the power supply

Voltage monitoring system revealed some periodic changes in the output voltage during long runs at COSY, hinting to a day-night cycle of the temperature variation. In order to carefully investigate the temperature dependance of the supply modules, a thermal chamber was built from 6 cm thick XPS material. Heater element, consisting of power resistors and heatsinks, was installed at the bottom of the chamber. The cooler element was constructed using a Peltier element sandwiched between passive (internal) and active (external, with fan) heatsinks. This configuration allows to change the temperature of the inner volume within -8 °C and +17 °C with respect to the ambient temperature. Temperature was monitored by a digital sensor DS18B20 run by a Raspberry Pi computer.

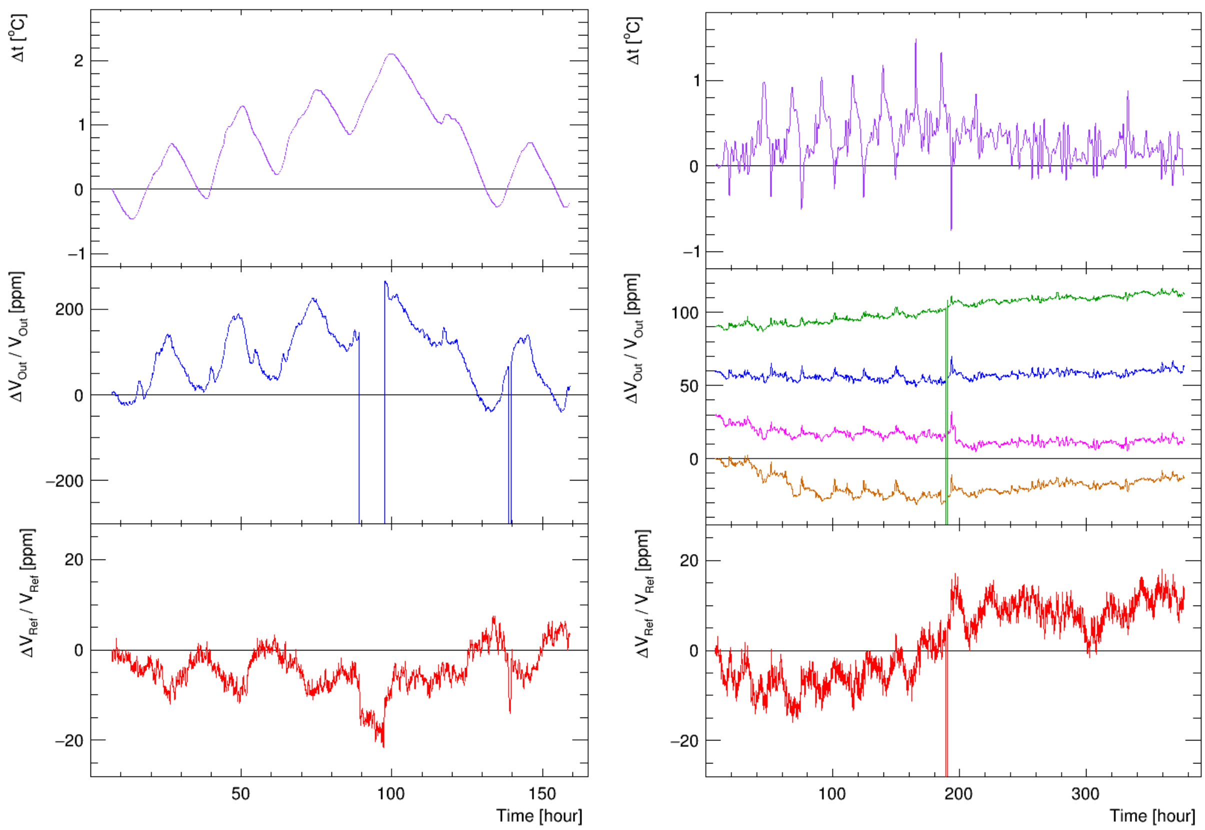


Figure 11. Voltage and temperature recordings before (left) and after (right) the stability improvement

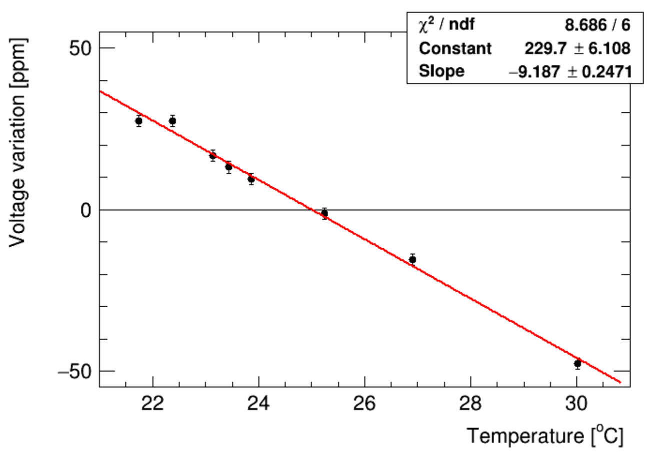


Figure 12. Temperature dependance of the final version of the power supply module, measured with a thermal chamber

The test of the supply module with the thermal chamber revealed a significant temperature coefficient of around 3 mV/°C at 30 Volts. After that all different components of the supply module were investigated and a mathematical model reconstructed to describe the temperature dependance of the whole module. This helped to identify the ways to reduce and/or compensate the temperature effects. Updated modules showed much improved temperature stability, by factor of 10 at least.

2.1.4 Slow control software of the power supply

The slow control and monitoring software of the power supply was developed based on Python and Raspberry Pi 3 computer, which is installed inside the power supply. RPi runs a web server which allows for connection from a remote computer and control of the power supply. Second part of the software – the client, is based on Qt graphical library. It provides the control buttons for each individual supply module, arranged in a shape of the actual calorimeter and smart voltage monitoring and statistics. The later feature allows to directly spot any possible instabilities of the supply voltages. The software also features the EPICS (Experimental Physics and Industrial Control System) support, providing the possibility of an automatic operation by the COSY control software. This allows to synchronize the calorimeter detector on/off with the COSY beam cycles. Besides, the voltage values is also shared with the EPICS system and can be monitored remotely.

Figure 13. A GUI interface for the power supply slow control

2.2 Polarimeter software

2.2.1 Data acquisition and online analysis system of the polarimeter

In order to achieve the best possible performance from the calorimeter, a high quality data acquisition hardware is vital. A 16 channel Flash ADCs (Struck SIS3316) have been selected for this task. They provide almost deadtime-less operation at 250 MS/s and 14 bis resolution, independently for all channels. In addition, these modules can be synchronized for scaling up the number of channels. Six such modules are used in the current setup. The provided time resolution corresponds to 4 ns. However, these modules provide hardware-based solution to make a linear approximation between the samples and estimate the time delays between the channels with precisions down to tens of pico seconds.

The configuration of the FADC modules and the data readout and rescue are provided by the standard data acquisition software, which was developed at Juelich and had been used for all other detectors as well. Another part of the polarimeter software – the online analysis part was mainly developed at SMART|EDM_lab, based on C++ and CERN ROOT libraries. It consists of two parts. The server-side part retrieves the binary data (from files or from socket connection) and runs different analysis modules, while the client-side part (can be run on the same or on a remote PC) retrieves the analysis results and displays them.

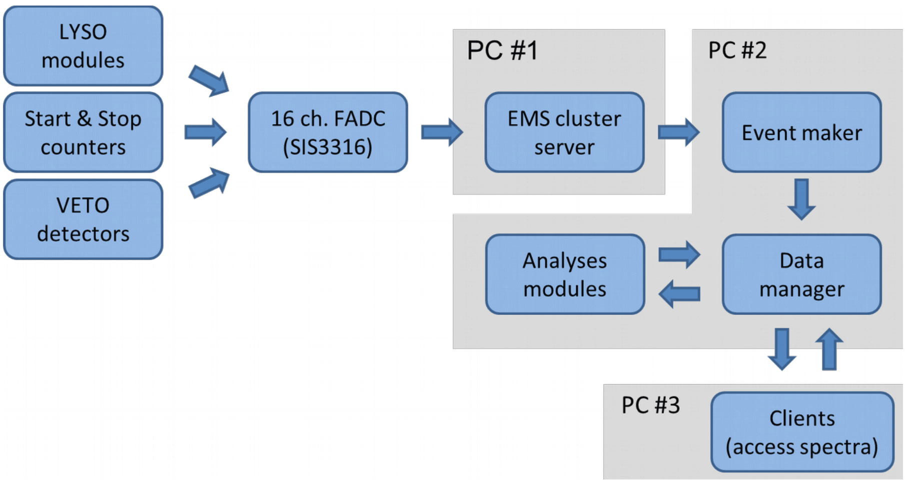


Figure 14. A logical scheme of the data acquisition and online analysis system of the polarimeter

The server-side part of the software consists of the following parts:

- **EMS server** – retrieves the raw data from FADC modules and writes them to disk (standard data acquisition software). Another copy of the data is sent via a socket to the online analysis;
- **Event maker** – retrieves a stream of raw unsorted data from the EMS server, sorts them depending on the acquision mode of the FADC modules and finally, produces event-base data. All the FADC channel information are now stored in a specific CFadcData container, which are then combined in a CFadcEvent.
- **Data manager** – retrieves container-wrapped sorted data from Event maker. All the different analysis modules are registered in the Data manager and analyse every event received from the Event maker.
- **Analysis modules** – all these classes are inherited from a virtual **CAnaBase** class. Their purpose can be different; from just producing amplitude spectra for every LYSO module to measuring the online polarisation of the COSY beam. The following analysis modules have been developed so far: CAnaCOSY, CAnaStats, CAnaLYSO, CAnadEvsE, CAnaElSelector, CAnaElAsymm, CanaEventWriter.

The online analysis software can be configured. An independent graphical configuration tool, based on Qt libraries, has been developed at High Energy Physucis Institute (HEPI) of TSU. It allows to manipulate with the polarimeter configuration, including geometry, module specification, ADC channel connections etc. An addition class – **CdaqConfig** was developed to provide an interface for the online analysis software to the polarimeter configuration.

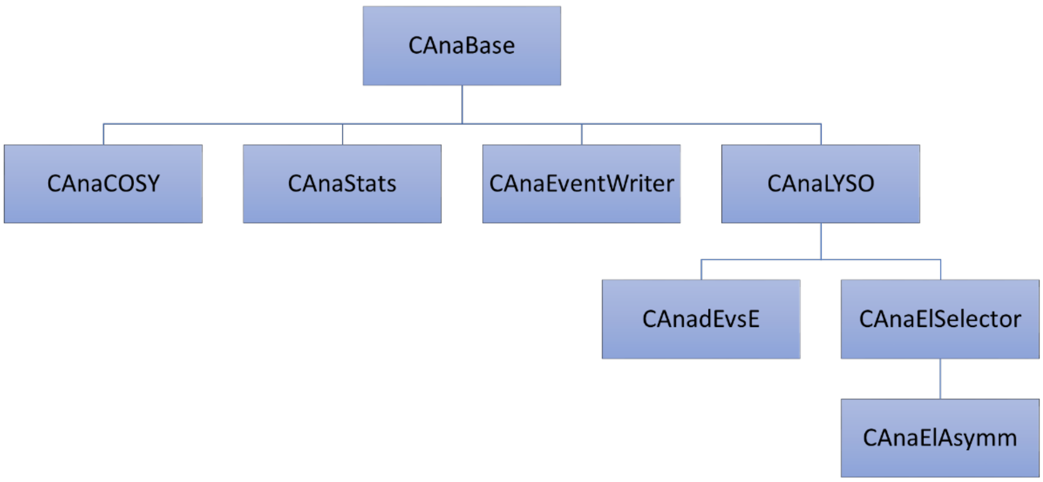


Figure 15. A hierarchy of the online analysis classes

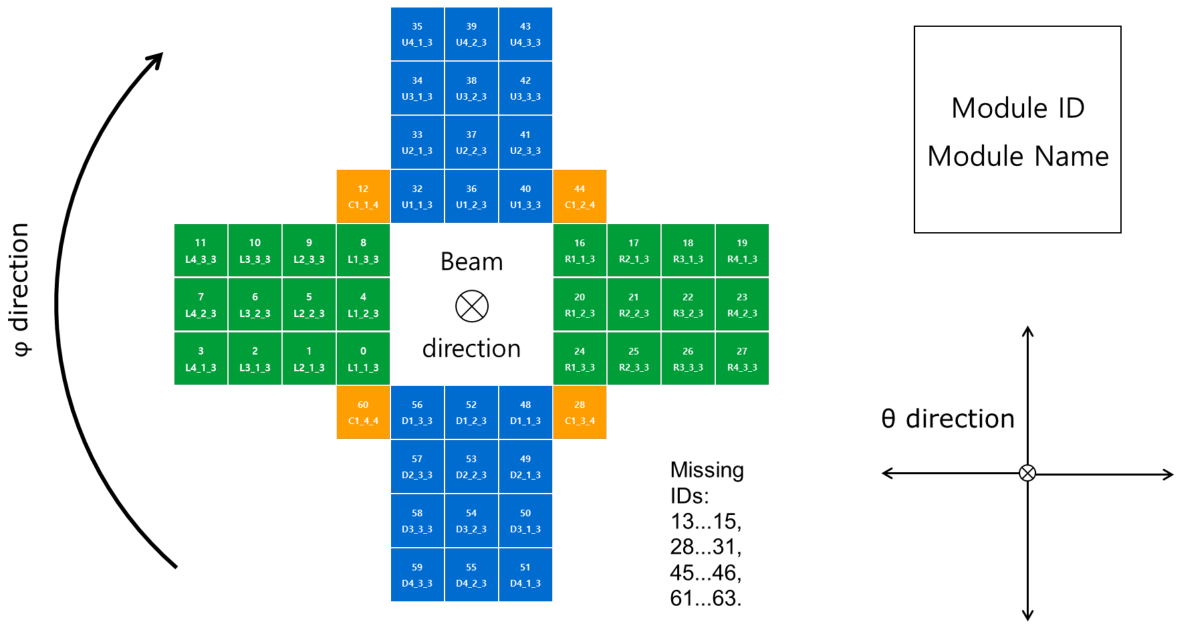


Figure 16. The geometrical arrangement and the naming scheme of the calorimeter modules.

The client-side part of the software is based on **CAnaClient** class. It establishes a socket connection to the running **Data manager** and retrieves online data from the registered analysis modules. All or only specific set of histograms can be retrieved from any analysis module. This class uses **CHistInterface** class which is responsible for the visualization of the results. **CHistInterface** uses configuration files to adjust all the canvases, pads and distribute histograms in these pads.

2.2.2 Portable data acquisition and online analysis system

It was noted earlier in the text that the Red Pitaya STEMlab 125-14 board was used to test the polarimeter power supply modules. Although this device is provided with web-based oscilloscope software, we have developed a portable data acquisition software to increase the capabilities of the board. It provides features similar to that of the polarimeter software. Since the computing resources of the board are limited, only least necessary processing is done on the acquired data by the board. The data are then sent to client-side part of the software, which is based on CERN ROOT. Here the main processing is done and the results are displayed. The client-side part also provides GUI, which allows the access to all the configuration features of the board.

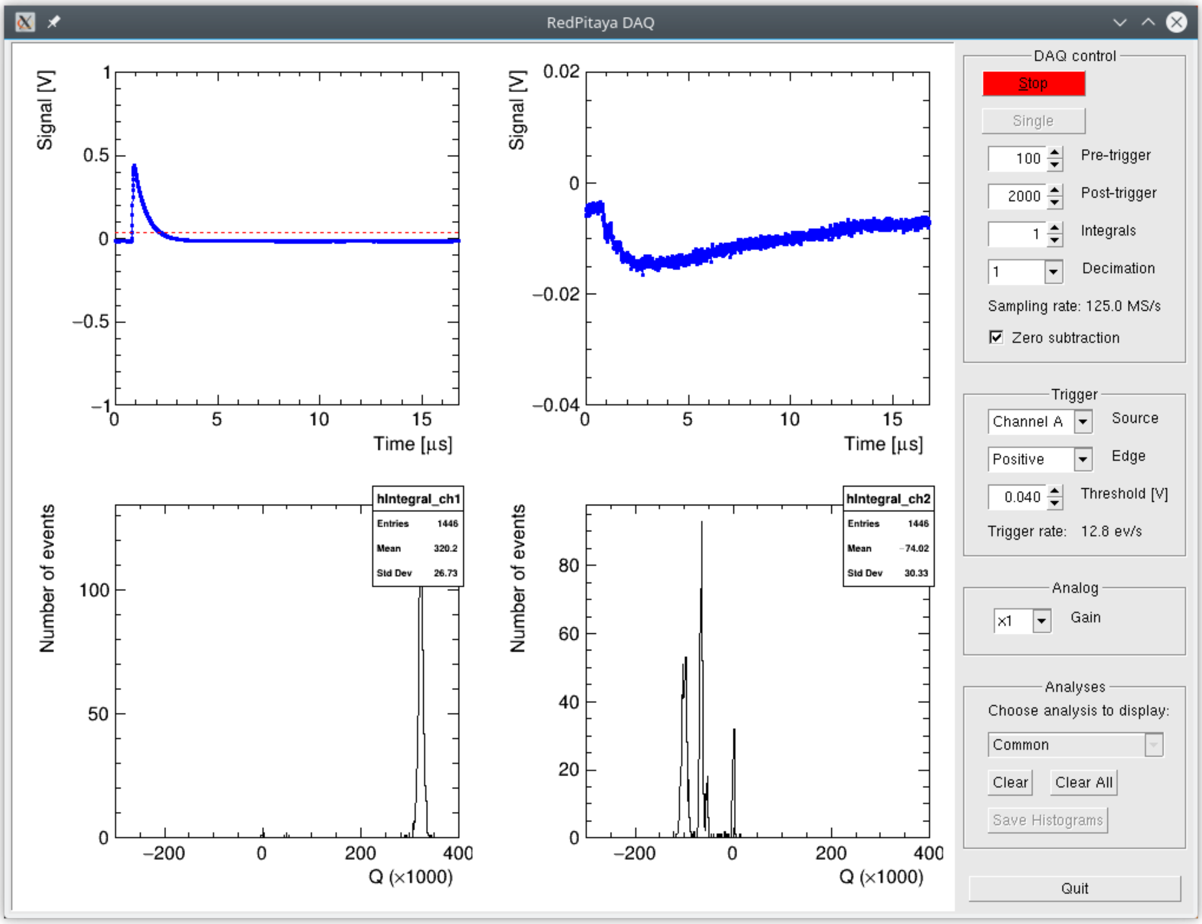


Figure 17. The GUI interface of the portable data acquisition and analysis system for the Red Pitaya STEMlab 125-14 board

The client-side part of the software consists of the following classes:

- **RPreader** – the main class. Provides all the necessary functionality, including communication with the board and an initial data processing (data calibration in voltage units and time axis formation)
- **RPreaderGui** – Provides GUI.
- **RPconfig** – Configuration class managed by configuration files.
- **RPanalysis** – A simple analysis class. Builds the signal shapes and the amplitude distributions.
- **RPAvShape** – Same as RPanalysis, but averages signal shapes. Useful with noisy signals.
- **RPshape2D** – Produces 2D waterfall plots for the signal shape.

- **RPtreewriter** – Writes the acquired data in ROOT files using a tree structure.

This portable data acquisition system is successfully used at SMART|EDM_lab for various laboratory tests as well as at Juelich to test different detectors with comic's and radioactive sources.

2.3 Joint project with SMART|AtmoSim_lab

Within the main research topic of the SMART|AtmoSim_lab – the study of the air pollution and related chemical processes in the atmosphere - the first prototype of a dedicated portable data acquisition and analysis system has been developed to work with well-established analog gas sensors from AlphaSense. It uses Arduino Nano platform to readout the analog signals from the sensors, apply calibration and other factors and calculate the final concentrations of different gasses in the atmosphere. The sensitivities of the sensors change with temperature. Thus, in order to account for these effects, an independent digital temperature sensor is also included in the system. All these data are then stored to a SD card, which is attached to the Arduino board. In addition, the time information from the RTC module is also written together with the concentrations. This allows for easy tracking of the obtained data in time.

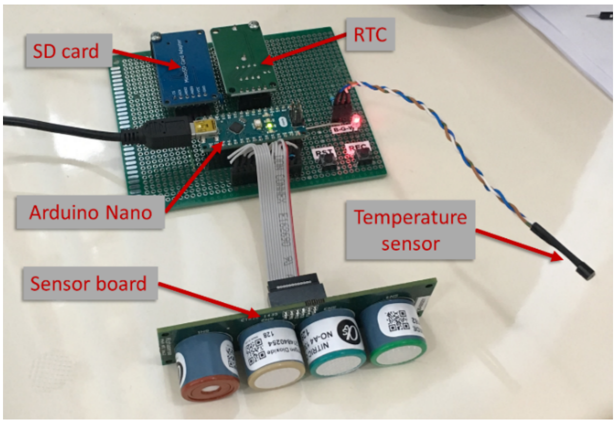


Figure 18. A portable data acquisition system (first prototype) for the gas sensors

This portable system was tested in different conditions and the results were compared to that of stationary, high precision laboratory equipment. A good agreement between the two sets of data is very encouraging for further development of such systems. Such portable monitoring systems can be powered from batteries and used at any place. The idea is also to mount them on the drones at some point and investigate the atmosphere in different locations and at different altitudes.

2.4 Educational components

All above-mentioned activities included educational components aiming to gain hardware and software skills of the involved students. These skills include programming on C/C++ and Python, using CERN ROOT environment and libraries, statistics, data analysis, data visualization, data interpretation. The students got familiar with modern methods of measurements, data acquisition, transmission, online and offline analysis, the principles of operation of various hardware tools, communication with the hardware. These activities also involved many aspects of electric engineering – investigating and using detailed specifications of electronic components, estimating their effects on the performance of the device, simulating, building and testing of the electric circuits.

3 Main participants and student's involvement in the project

All the activities at SMART|EDM_lab are supervised by the head of the laboratory – David Mchedlishvili. The dedicated funding for travel allows to efficiently transfer obtained results, gained experience and achieved goals between SMART|EDM_lab and Juelich.

The budget of the project includes the funding of one PhD student during three years and Master's students every year. A PhD student of TSU – Dito Shergelashvili has been promoted to this position. He was working on his Master's thesis at Juelich, in the framework of JEDI collaboration. His responsibilities at SMART|EDM_lab include development and improvements of the calorimeter modules, examining the capabilities of the data acquire hardware, online and offline analysis and other hardware and software systems for the polarimeter.

The first Master's student – Otari Javakhishvili was involved in the activities at SMART|EDM_lab during one and a half year and successfully made his Master's thesis on the topic "Power Supply Development for JEDI Polarimeter". He is now doing his PhD thesis at Juelich under the supervision of Irakli Keshelashvili.

During the later periods other Master's students were also involved in the ongoing activities at the lab:

- Giorgi Kvantrishvili from TSU was involved in the development of software modules for the polarimeter.
- Mikael Gagoshidze from the Engineering department of the Agricultural University of Georgia (AUG) was involved in the investigation and improvement of the temperature stability of the power supply modules.
- Mariam Abuladze from the Engineering department of the Agricultural University of Georgia (AUG) was carrying out the detail Monte Carlo simulations of the JePo polarimetry concept during her Master thesis work.
- Irakli Lomidze from AUG is now involved in the further development of the online and offline analysis software (Master thesis).

In addition, the following Bachelor's students have also been involved in various activities: David Kordzaia (AUG), Rati Chkhetia (AUG), Giorgi Chaduneli (AUG), Mariam Mukbaniani (TSU), Valentina Sarkisova (TSU), Lana Rekhviashvili (TSU), Dachi Okropiridze (GTU).

4 Scientific productivity

The list of talks reported on international conferences and meetings:

- Dito Shergelashvili - „LYSO module assembly and laboratory tests", Juelich, Germany, March 6-7 2017;
- Otari Javakhishvili - „Development of Voltage Supply system for SiPM arrays", Juelich, Germany, March 6-7 2017;
- David Mchedlishvili - „JEDI polarimetry: Developments at SMART|EDM_Lab", Tbilisi, Georgia, September 30 2017;
- Dito Shergelashvili - „Lab tests of the JEDI polarimeter modules", Tbilisi, Georgia, September 30 2017;
- Otari Javakhishvili - „Power supply develoment for JEDI polarimeter", Tbilisi, Georgia, September 30 2017;
- Dito Shergelashvili - „LYSO modules for the JEDI polarimeter: production, laboratory tests and first results", Daejeon, Republic of Korea, October 16-20 2017;

- Dito Shergelashvili - „Development of LYSO Detector Modules for an EDM Polarimeter at COSY“, Bochum, Germany, February 28 2018;
- Dito Shergelashvili - „Development of LYSO detector modules for a charge-particle EDM polarimeter“, Ferrara, Italy, September 10-14 2018;

The list of published papers (connected with the JePo development):

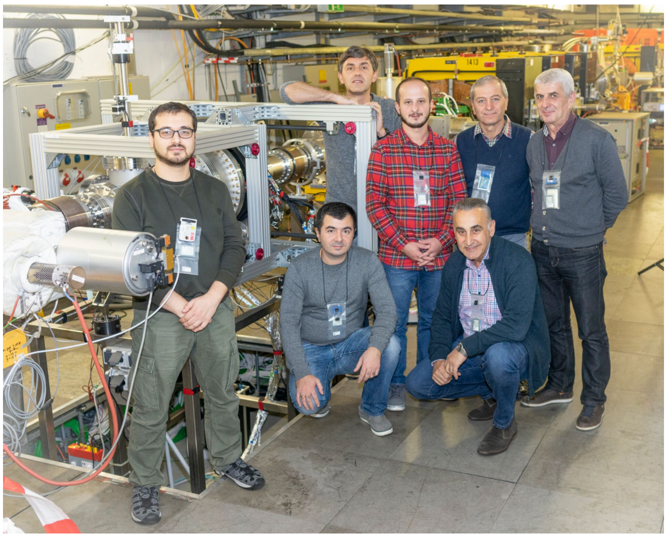
- O. Javakhishvili *et al.* – “Development of a multi-channel power supply for silicon photomultipliers reading out inorganic scintillators”, **NIMA 977, 164337 (2020)**
- F. Müller *et al.* – “A new beam polarimeter at COSY to search for electric dipole moments of charged particles”, **JINST 15, P12005 (2020)**
- I.Keshelashvili *et al.* – “Development of a modular calorimeter based on LYSO scintillator crystals with SiPM readout”, **JINST ??, ?? (2021)**

The list of the JEDI collaborattive papers contributed by TSU group (2016 – 2021):

- G. Guidoboni *et al*., - «How to Reach a Thousand-Second in-Plane Polarization Lifetime with 0.97 GeV/c Deuterons in a Storage Ring», **Phys. Rev. Lett. 117, 054801 (2016)**
- N. Hempelmann *et al*., - “Phase Locking the Spin Precession in a Storage Ring” **Phys. Rev. Lett. 119, 014801 (2017)**
- A. Saleev *et al*., - “Spin tune mapping as a tool to probe the spin dynamics in storage rings”, **Phys. Rev. ST Accel. Beams 20, 072801 (2017)**
- G. Guidoboni *et al*.,- »Connection between zero chromaticity and long in-plane polarizationlifetime in a magnetic storage ring», **Phys. Rev. Accelerators and Beams 22, 024201 (2018)**
- N. Hempelmann *et al*., - «Phase measurement for driven spin oscillations in a storage ring», **Phys. Rev. Accel. Beams 21, 042002 (2018)**
- F. Mueller *et al.*, - «Measurement of deuteron carbon vector analyzing powers in the kinetic energy range 170 – 380 MeV» , **Eur. Phys. J. A 56:211 (2020)**
- S. Karanth *et al*., - «Influence of electron cooling on the polarization lifetime of a horizontally polarized storage ring beam», **Nucl. Inst. and Methods in Physics Research, A 987, 164797 (2020)**
- T. Wagner *et al.*, - «Beam-based alignment at the Coller Synchrotron COSY as a prerequisite for an electric dipole moment mesaurement», **JINST 16 T02001 (2021)**

5 Summary & Otlook

The topics described in this report constitute the main part of the SMART|EDM_lab activities during the five years of operation. The focus was made on the activities which had been performed primarily at SMART|EDM_lab. The participants of the project remain in the active collaboration with the JEDI experiment and all related activities planed in frame of recently formed CPEDM collaboration (reference to CYR: https://e-publishing.cern.ch/index.php/CYRM/issue/view/132)



From left to right: Otari Javakhishvili, David Mchedlishvili, Irakli Keshelashvili, Dito Shergelashvili, Andro Kacharava, Mirian Tabidze and Nodar Lomidze.

As was noted the JePo is already installed at COSY and is being successfully used for EDM-related measurements. However, it is not yet complete. The tracking part of the detector is not yet assembled and installed. When finalized, it will provide track reconstruction possibility and thus, much better angular resolution. In addition, it will provide partial energy loss data in the thin scintillator, which together with the total energy loss data inside LYSO modules allows for much cleaner identification of the elastic scattering events. The concept of the tracking detector part was simulated with GEANT. The few modules were also tested with extracted beam at COSY and demonstrated a good coincidence with the simulation. It is necessary to further test larger set of tracking modules with internal beam. The software part has also to be developed and integrated into the online analysis system.

The power supply of the JePo polarimeter can be further improved. The achieved stability level of the output voltages leads us to the idea of using software feedback system to compensate for the temperature effects of the LYSO material and the SiPM. This will bring the stability of the calorimeter modules at even higher level. In order to achieve that the further modification of the supply modules will be necessary. A remote voltage adjustment feature will have to be implemented.

JePo now uses carbon block targets. The idea for the final version is to use an innovative type of the target – Ballistic Pellet Target. Although proving to be the ideal concept for srEDM measurements, it requires quite complicated pellet tracking and mechanical systems to be developed beyond the state of the art. These developments have already been started at Juelich and SMART|EDM_lab will contribute in this direction.

The laboratory also plans to further contribute to SMART|AtmoSim_lab's activities. The portable data acquisition system for the sensors can be further improved and tested in various conditions. There are many ideas of using such portable systems beyond the basic research, motivating for the further development.

The experience and the expertise gained in the development and the activities described in this report can be successfully used in other directions of the applied and basic research, where particle detectors are used. Moreover, many of such systems are used today in medical imaging technologies. Should be noted, that the similar materials and devices (LYSO, SiPM) are also used in PET imaging. Modern medical imaging technologies tend to combine together two or more systems, like MRI-PET. The use of SiPM-s is essential in these systems due to their ease of use inside the strong magnetic fields unlike to conventional PMTs. There are several ideas to improve the conventional PET constructions by applying technics similar to that used in the tracking part of the JePo polarimeter. This has potential to simplify the PET structure, reducing the cost, minimize the radioactive dose the patient receives from the agent. However, these ideas have to be carefully examined and verified at PET energies. These activities can be performed at SMART|EDM_lab at TSU.